

TLS-Dicing – The Key to higher Yield and Throughput for thin Wafers

Hans-Ulrich Zuehlke*, Gabriele Eberhardt*, Ronny Ullmann*, Mike Lerner**

*JENOPTIK Automatisierungstechnik GmbH

**JENOPTIK Laser Technologies

Konrad-Zuse-Str. 6

Jena, Germany, 07745

+49 3641 65-3980, Fax +49 3641 65-133890

hans-ulrich.zuehlke@jenoptik.com

ABSTRACT

Thermal Laser Separation (TLS)-Dicing is a fast, clean and cost effective alternative to known dicing technologies. The process uses thermal induced mechanical forces to separate brittle materials such as Silicon, GaAs. Thermal stress is introduced in a well defined region via a laser beam. Cooling is applied via a Di-water-spray. The induced forces separate brittle materials by cleaving. TLS is a true cleaving process which results in an edge with excellent quality, without chipping or micro cracks. This high edge quality results in a significantly higher mechanical breaking strength and an increased blocking voltage for vertical integrated devices. TLS Dicing is a zero kerf process which has the potential to reduce street width and increases yield. The maximum TLS-dicing speed of 300 mm/s is much faster than any other dicing technology for thin wafers. This paper will discuss the theory, benefits and limits of TLS. A comparison of TLS with other laser dicing technologies will also be presented. To conclude, this paper will provide the latest results achieved by TLS and an overview of the JENOPTIK TLS tool.. TLS is a interesting alternative for sawing and ablative laser dicing technologies as well as an enabling technology for new products. TLS is especially well suited for RFID, dies for 3D-stacking, flexible products (chip cards), MEMS, optical devices and thin dies (e.g. power devices or solar wafers.)

Keywords: Dicing, Cleaving, Yield Enhancement, Dicing Speed

BASICS OF TLS-DICING

Thermal-Laser-Separation (TLS) uses very simple effects to separate brittle materials. A very small, punctiform initial scribe (I-Scribe) is required to initiate separation (see figure 1, step 1) and to give the subsequent cleaving step a defined starting point. This initial scribe must be done with a diamond tool tip or via a low power pulsed laser). After this initial scribe, cleaving is initiated by inducing thermal stresses. This is achieved with a combination of heating (by a laser) and cooling (by a water-aerosol mixture). The laser, optical system and cooling nozzle are integrated into a single unit, which traverses the wafer along the desired separation line. The material is heated up by a laser with a well defined quantum of energy (step 2a). As the heated material expands, pressure forces occur within the heated zone. Simultaneously, tangential tensile stress occurs around circumference of this zone (TF I). The laser

beam is immediately followed by a cooling spot. The cooling spot causes the material to shrink, thereby inducing radial tensile forces in the zone (figure 1, step 2b, TF II). At the overlaying zone (between the heating/cooling stresses) the two tensile forces are additive. At this location, the reinforcing forces are strong enough to open / draw the crack through the material (figure 1, step 3).

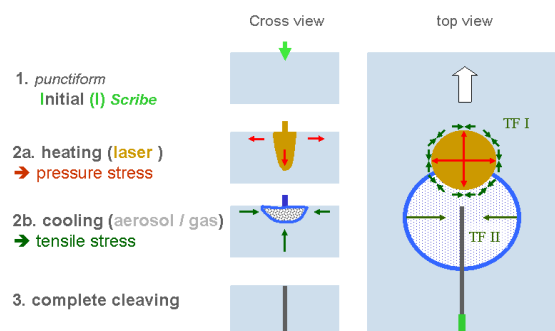


Figure 1: The principle of TLS-dicing

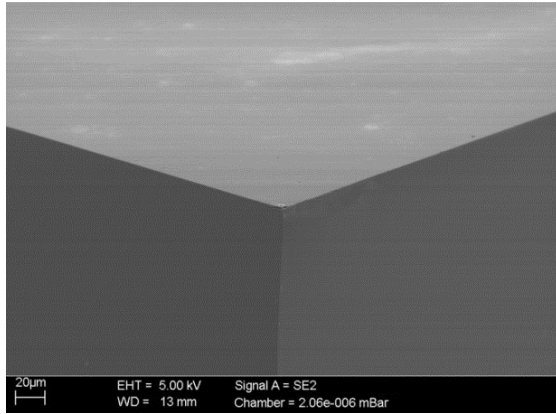


Figure 2: SEM-picture of the resulting TLS-diced edge

For crystalline materials like Silicon, GaAs or Germanium complete separation is achieved. The separation is independent the lattice plane – this is also the reason, why the initial scribe is needed to define the starting point. The result is a separation with excellent properties of the die (see figure 2).

The edges are very smooth, without chipping or any notable damage. The position of the cleave is very well defined along the line of movement of the heating/cooling spots. The cleave is self centring because the stresses are only high enough to propagate the crack at the exact intersection of the local maximums of the heating stresses and cooling stresses. If the crack tends to be faster (than the tool combination of laser and cooling) the crack runs into the zone of pressure forces, and will be delayed. The only risk to “lose” the crack is, when the tools are running faster than the crack-opening itself. The maximum traverse speed must be determined empirically for different bulk materials and layers. Typical speeds are between 200 mms/s and 300 mm/s.

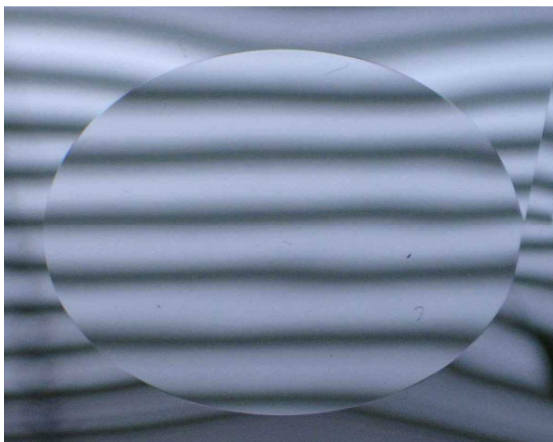


Figure 3: TLS-Dicing is independent of the lattice plane – this is demonstrated by a circular cut the visible stripes are only shadows to make the circle visible)

BASIC CONDITIONS AND LIMITS OF TLS-DICING

There are several important factors and basic conditions critical to the TLS process. The TLS-process requires the material to have a high coefficient of thermal expansion (CTE). TLS is not applicable to materials with a low CTE (like typical fused silica). Higher laser energy will not overcome a low CTE because of the risk of thermal destruction effect at the wafers surface. (However some new, higher CTE formulations of fused silica have been created for encapsulation of Si wafers have.) TLS-technology is based on thermally inducing mechanical stresses in the material. In the case of very thin wafers, the heated / cooled volumes are extremely small. Therefore, the forces generated may not be sufficient to guide and draw the crack. In some cases, only a temporary deformation will occur. Successful TLS results have been proven for wafers down to - 30 µm thick. Ongoing tests are needed for wafers below 30 µm. TLS's upper limit (for wafer thickness) depends mainly on the laser power, and the specific heat conduction of the bulk material. So Si-wafers up to 250 µm and GaAs-Wafers up to 675 µm can easily be cleaved with a 200 W laser system. Thicker wafers could theoretically be cleaved using a higher powered laser. However, the limiting factor can be the effectiveness of the heat-conduction based cooling.

The crack front in the material will be well defined if the induced stress in each case dominates locally. As long as there is one defined local maximum, cleaving even can be done independent of the lattice plane (Figure 3). Special actions may be required to stabilize the process when cleaving near the border area of the wafer should be done. Similarly, the position of the cleaving line may vary slightly at the grain boundaries of multi crystalline wafers (within micrometers).

The geometry of the laser spot is designed to be small enough for the dicing street and have enough are to couple in the laser energy below the level of thermal destruction of the wafer surface. The width of the laser spot determines the minimum required street width (typically 30 µm). The length of the laser spot is one factor which determines the minimal treatable edge length of the die.

Absorption and reflection are important factors in all laser applications. The absorption depth varies depending on the laser wavelength. For guiding the well defined crack front, a balanced heating of the surface and inner regions of the material is required. To achieve this result in silicon a laser wavelength in the near infrared spectrum (NIR, 1030 ... 1080 nm) is used. It is necessary to consider the changes of modified optical properties, caused by functional layers, e.g.

surface passivation layers. Some of the layers are strongly absorbing and can be destroyed thermally by the laser, if no special actions are taken. A high percentage of reflecting metallization (e.g. process monitor fields) within the dicing street can also disrupt the separation. Smaller structures will be separated without any problem (see figure 4).

Since the cooling medium doesn't contact the inner material, heat dissipation must be achieved via heat conduction. Therefore, the time required for heat dissipation via conduction is a limiting parameter for the cleaving speed. In contrast to other laser technologies, the speed can not be increased significantly by using a higher powered laser. Typical cleaving speeds are between 200 and 300 mm/s. For thin wafers, this is faster than other dicing technologies (see figure 8). The TLS process only heats the material for a few milliseconds. Computer simulations showed that the maximum temperature in the material should be 400° C or below. This maximum temperature is only reached for a very short time. These computer simulations have been empirically proven by analyzing actual TLS results under the microscope. Layers of low melting point materials within or near the dicing street verify that the maximum temperature in the material is less than 400° C. These results were further verified by analyzing photoluminescence heterodyne (PLH) measurements (one near the dicing street and one far away) (see [1]).

Semiconductor wafers have many structures and layers as a result of the different steps in the front end process. TLS has been evaluated to determine the affects of back-side metallization on the separation process. Experiments show that for wafers with typical metal layers up to 2 µm a complete separation is easily achieved. Because the mechanical forces must be generated within the bulk material, the ratio of the thickness (bulk material to metal) should be greater than 100:1. Given these conditions, the damage to the metallization edge is smaller than the thickness of the layer and without any peeling (figure 5).

TLS-DICING COMPARED TO KNOWN DICING TECHNOLOGIES

State of the art and competitive technologies

The classical dicing technology is mechanical sawing. A rotating saw blade cuts the wafer completely. This process requires a great deal of cooling and cleaning media, which then must be removed in a subsequent cleaning step. To avoid mechanical breakage or the release of dies from the dicing tape, thin wafers can only be

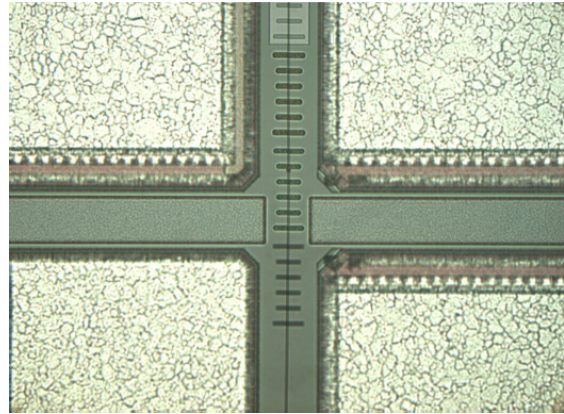


Figure 4: Cleaving result for metal within the dicing street

treated at reduced speeds (e.g. 30 - 50 mm/s for wafer thickness of 100 µm).

Ablation laser processes have an advantage for thin wafers, achieving dicing-speeds greater than 50 mm/s. Because the laser ablates a fixed volume per time, thinner wafers are processed at higher speeds. Lasers with a small absorption depth can be used to selectively ablate surface layers (e.g. 532 nm and below for silicon). One disadvantage of laser ablation is that residues are created from the evaporated or melted material. Most suppliers of ablation laser systems recommend protecting the wafer temporarily with an additional protection layer (e.g. PVA). Regardless of the exact ablation technology used, some Heat affected zone (HAZ) will result. Obviously, the severity of the HAZ depends on the exact laser/material of the application in question. The resultant bending strength of the die is relatively low because of the significant edge damage caused by the ablation process.

The laser-micro-jet (LMJ) process is also an ablation laser technology. In LMJ a water beam is used as a light-guide. One outcome of LMJ is that the water cools and cleans the working zone. However, LMJ has the disadvantages of using water and the reliability/maintenance of high pressure components.

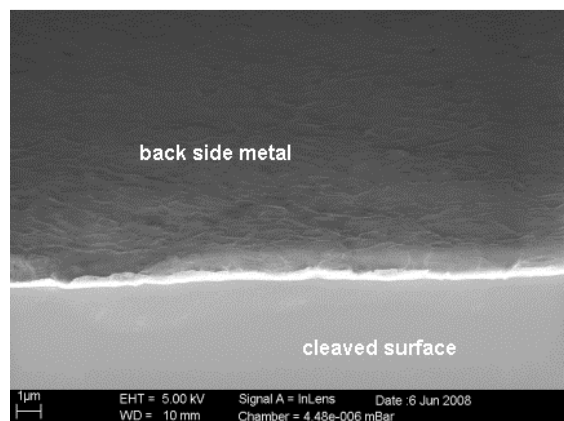


Figure 5: Die edge with back-side metal layer

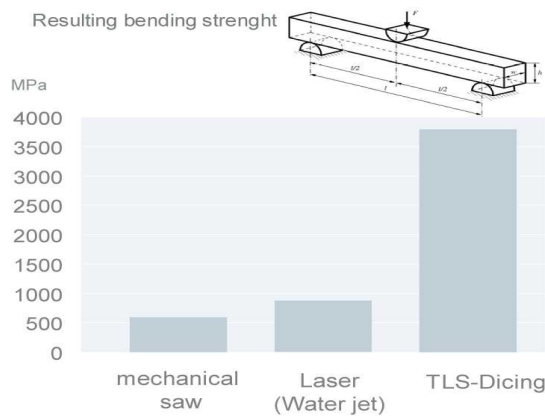


Figure 6: Bending strength comparison

Stealth-dicing induces separation by modifying a small inner layer of the wafer material. The surface is not influenced. This technology has some similarities to TLS. However, Stealth dicing does not produce the same smooth and undamaged edge quality. Another issue is that the position and properties of the modified amorphous separation zone depends on the varying relation between laser wavelength and dopants. The Stealth process modifies up to 50 μm -thick layers in a single pass. However the processing speed is reduced for thicker wafers, as multiple passes are required for separation. Furthermore, complete separation of the die is not achieved until the wafer undergoes a secondary processing step (stretching of the tape). A further limitation is the required minimal street width (50 % of the wafers thickness).

Properties of TLS-Dicing (Advantages and limitations)

TLS has several important advantages for (i) front-end process (ii) back-end process and (iii) quality of the end products. Some benefits can be realized immediately (e.g. higher bending strength by reduced chipping). Further advantages of TLS can be achieved in new product design cycle. (e.g.

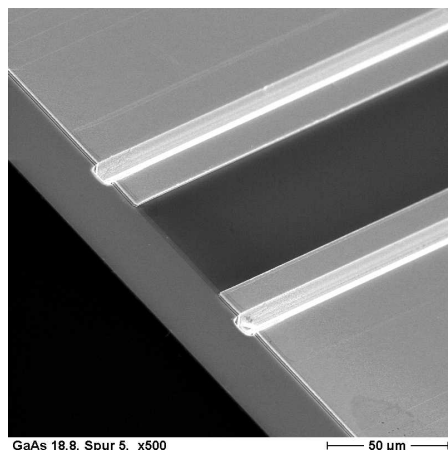


Figure 7: TLS-separation on GaAs-wafer with optical device

increased yield by reduced street width). TLS also has the potential to enable new products such as Complex Multi-Product Wafers (CMPW) with irregular die geometries or segmented solar cells.

The **mechanical properties** of a die are important. Improving the mechanical strength of the die has benefits both for manufacturing (i.e. handling of the die) and also when the chip is in use (i.e. the chips ability to withstand thermal stress).. Additionally, a dies bending strength has a significant influence on yield. The major factor determining the bending strength of the die is the quality of it's diced edges. Bending strength is greatly reduced by defects on the edges that result from sawing, cutting and grinding. Bending strength of TLS diced samples are determined using a three point bending test [2]. These tests proved extraordinarily high values for bending strength (much higher than for all other dicing technologies - see figure 6).

Furthermore, the **electrical properties** of a TLS cleaved edge are superior. This is especially evident in the blocking voltage achieved for vertical integrated devices like IGBT or solar cells. These blocking voltages are much higher with TLS due to the minimal HAZ and the mirror- smooth edge.

Improved purity: TLS is the cleanest of all dicing technologies. The cleaving step does not generate any particles. The mechanical I-Scribe is ideally a plastic impact, realized by a force sensitive and controlled scribing tool. Under these conditions the particle measurements have proven that contamination levels in TLS process are insignificant. In fact, the measured particle counts are comparable with an untreated reference wafer. Expensive preparations before (or cleaning after) dicing is not necessary. The cooling media (mostly DI-water) is removed during the dicing process. A small amount of water (10 ... 15 ml/min) is used which could damage water sensitive wafer surfaces. As a further improvement to the process, alternative dry cooling medias (e.g. cooled gases) are being investigated. TLS with dry cooling will be the ideal tool for the dicing of MEMS-devices.

The **optical properties** achieved with TLS are comparable to the excellent quality of cleaved edges of the mechanical scribe & brake processes (see [3]) used for separating LED's and laser diodes on GaAs (see Figure 7).

Yield can be increased in several ways. Damage free edges and the resulting higher breaking forces reduce yield losses after dicing. A very significant yield improvement can also be achieved by reducing the width of the dicing streets. Wafers designed for mechanical sawing have street widths from 50 to 100 μm (the cut trench is typical 30 μm wide). For stealth dicing the street width must be 50% of the wafer thickness. In comparison, the streets for TLS can be minimized

to 30 μm (the typical width of the laser spot). A true zero kerf separation is achieved because TLS is a cleaving process. The reduction of the street width has the highest effect for projects with small dies and many dicing streets. For projects with large dies a significant amount of the wafer area could not be used, as long as the chips are arranged in regular columns and rows. TLS-Dicing has the ability to separate irregularly arranged dice (as in **CMPW** applications). In this case, yield can be increased via the reduction of “throw-away” sections of the wafer. Furthermore, because TLS greatly reduces edge damage and HAZ the passive safety zone around the die can be reduced (also increasing yield).

Potentially, **the throughput** of the TLS system is much higher than for sawing or laser ablation technologies. TLS is a two-step process (I-Scribe then Cleave). The positioning speed of the diamond tool (for the I-Scribe) is very significant to TLS's total process time. Therefore, by replacing the diamond tool with a laser (no mechanical repositioning) the total process speed can be increased significantly (vs. standard TLS). Furthermore, with standard TLS, the I-Scribe/Cleave processes are performed in series. Once the I-Scribe is done at a second working place (Chuck), it allows the I-Scribe/Cleave steps to be performed in parallel – the resulting speed will similar to the cleaving speed of 300 mm/s (see figure 8).

Cost of Ownership: The mechanical saw is a relatively small investment. However, tool wear is a problem and the saw blade must be changed at regular intervals, depending on the dicing parameters. Additionally, wafer hardness has an influence on the sawing process and metals/low-k-materials can stick to the blade, resulting in a premature replacement of the blade.

The initial investments for laser systems are relatively high when compared to a saw. In

some instances, the laser is a complement to rather than a direct replacement of the saw (e.g. low-k-grooving). The operational costs are quite different for different laser technologies, but TLS has one of the lowest: The TLS laser has a very high MTBF. No expensive consumables are used (only a minimum amount of Di-water). No protective coating before, nor cleaning after dicing is required. The TLS system has virtually no tool wear (except for the scribing diamond).

CURRENT AND POTENTIAL APPLICATIONS

The TLS-Dicing-Technology has been tested for many different wafer projects. Due to the confidentiality of most projects only some key data can be published: Silicon product wafers have been separated in the thickness range from 30 μm up to 250 μm . Many of these wafers came with different (thin) metal layers. Street widths have been tested between 30 and 75 μm . Ge-wafers (2 inch wafer, 150 μm thick) have been separated in to dies of 2 X 2 mm². GaAs wafers (4inch wafer, 100 μm thick) have been separated into dies of 1 X 0.8 mm².

In general TLS-dicing is optimal for separation of vertical integrated devices (like IGBT) or even solar cells due to the superior blocking voltage that is achieved. The dry cooling option will be the key for dicing MEMS-products. An additional benefit for MEMS is the separation without any mechanical vibration or particle generation.

TLS cleaved dice have a very high bending strength. This is very valuable for thin and flexible products (like RFID and smart-card-dies) as well as for products with rough handling after the separation (like solar cells).

For SiC-wafers first results have been very encouraging and applications are on-going.

THE TLS-DICING-SYSTEM

The TLS-dicing-technology was developed by a funded project, together with scientific and industrial partners. For the comprehensive assessment within this project a prototype system was built (see figure 9).

The main properties of this prototype system have been evaluated in the clean room. (e.g. the reliable function of the automatic handling system, the particle generation, the precession of the separation, the functionality of the dicing etc.)

Some minor changes, based on the experience with this system have been done in the design and the first system has been sold.

The TLS-dicer is a modular system with a technology module (see figure 9 - left side) and

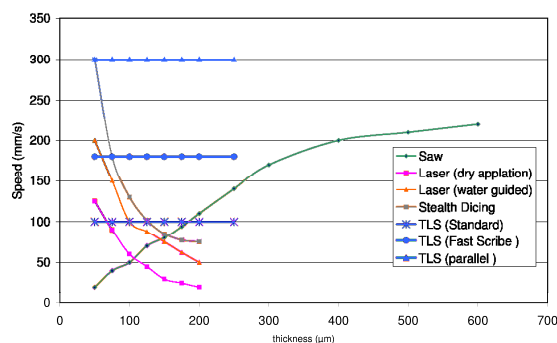


Figure 8: TLS dicing speeds compared to other dicing technologies (Please note that the data are collected from different sources: (publications and application reports from different suppliers and vendors).

additional functional modules like the automatic film frame handling system (see figure 9 - right side) or future options like a vacuum dryer. The tool can handle wafers of all diameters up to 300 mm. Typical dicing tapes can be used. To prevent sticking of the tape on the chuck (which may be caused by the laser irradiation at the edges of the wafer) the surface of each chuck is adapted to the wafers diameter and has to be changed. The changeover time is less than 15 minutes.

The TLS system uses a fibre-coupled fibre-laser with a guaranteed lifetime of 22500 h (the real life time is significant longer). The use of this laser source results in low maintenance and a minimal cost of ownership. The laser works in cw- (continues wave) mode and has a nominal power of 200 W.

For typical materials the straightness of the cleave line is $\pm 3 \mu\text{m}$, the sum of the oscillation value of the cleaving and the errors from the movement system. Since TLS is a zero kerf process, this accuracy results in an extremely narrow path (when compared with other dicing technologies.)

In the standard-version the system is designed for clean room class 6 and can also be used for challenging applications like 3D-stacking.

The active dicing time was optimized by using two cooling nozzles and using the system in a bi-directional mode. The cooling nozzles typically apply 10 to 15 ml DI-water per minute (during the cleaving process only). The water is dispensed by filtered compressed dry air or nitrogen.

As previously discussed, two different tools can be used for the I-scribe. The slower but cleaner version is the force controlled diamond tool tip. The other option is a small pulsed low-power laser to make the I-scribes (in the optimum case this is achieved at the same speed as the cleaving step). This laser ablates a very low amount of particles. The current I-Scribes are $10 \mu\text{m}$ wide and $6 \mu\text{m}$ deep. Reduction of the I-scribe profile is a subject of future development.

The standard TLS system is equipped with an alignment system. This alignment system includes a software based edge detection step which finds the correct positions for the I-scribes at the edge of the wafer.

CONCLUSION

TLS provides the highest quality edge of any dicing technology. Therefore, TLS is ideal for applications with special demands on edge quality (e.g. optical devices or power devices with vertical current flow). The process is clean and free of vibrations or mechanical shock waves. For standard products, especially on thin wafers, the high throughput, increased yield and the favourable cost-of-ownership are major advantages to TLS.

The process also works for the most Si-wafer-based photovoltaic cells.

The modular TLS-Dicing system was introduced to the semiconductor community in 2008. Extensions like complete dry cooling and the laser-I-scribe are the subjects of recent development.

TLS-Dicing will not replace the standard saw in all cases, but it opens many exciting possibilities for new products and can improve the process as well as the product properties in many cases.

- [1] Ehler, Andreas; Kersten, Michael; Lundt, Holger et. al.: Selected applications of photo thermal and photoluminescence heterodyne techniques for process control in silicon wafer manufacturing. In: Optical Engineering 36(02), 446-458, Brian J. Thompson; Ed.
- [2] Schoenfelder, S.; Ebert, M.; Landesberger, C.; Bock, K., Bagdahn, J.: Investigations of the Influence of Dicing Techniques on the Strength Properties of Thin Silicon, Microelectronics Reliability, 2007, 47, 168-178.
- [3] Acker, M.S.: The back-end process: step 11 – scribe and break. In: Advanced packaging, November, 2001.



Figure 9: The TLS-Dicing-System (prototype version for 200 mm wafers with automatic handling)